

Flow State Analysis on Abrasive Motion of Centrifugal Grinding under Different Working Conditions

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Abstract. The flowing behavior on abrasive grains was analyzed by two-phase flow dynamic model when using different duty parameter in planetary lapping. The results show that the duty parameter will affect and control grains flowing behavior in lapping process. Further, it is pointed out that duty parameter is important to enhance productivity. The parameters of design and technology can be optimized economically and efficiently with the method so as to improve working quality.

Introduction

The motion model based on solid and liquid two-phase flowing theory is established according to the basic hypothesis for motion of abrasive particle during the centrifugal grinding process[1]. The important goal to conduct numerical simulation for grinding process by using two-phase flow model lies: get to know the main factor that affects the motion form of abrasive particle in essence so as to optimize the design parameter of the equipment and parameter of processing technology through description and comparison of characteristic of flowing state of two-phase flow with different parameters.

We understand from the analysis for the motion model that the kinetics process for flow motion in the centrifugal roller is mainly determined by the following groups of parameters:

- (1) Relevant design parameters of the mechanical structure of planetary polishing machine, mainly including the revolution radius of gyration R and rotational radius of gyration r_0 .
- (2) Transmission characteristics of planet polishing machine, mainly including revolution angular velocity Ω and rotational angular velocity ω .
- (3) Transmission characteristics of abrasive particle and polishing solution (density ρ_s, ρ_l and viscosity coefficient μ_s, μ_l).
- (4) The initial filling rate of abrasive particle α_0 .
- (5) Shape and materials characteristic of planetary roller.

During the grinding process, the flowing state characteristics of motion of abrasive particle influence and control directly the processing of parts while the planetary transmission ratio of the equipment is the important factor to form the different flowing state characteristics of abrasive particles.

Selection of Working Conditions

Relationship between the Distribution of Relative Ratio of Centrifugal Force and Planetary Transmission Ratio: From the mechanical process of centrifugal grinding, the centrifugal force produced by gravity and rotation is the main force that drives the motion of mixed flow during the grinding process, and the dynamic characteristics of centrifugal force depend on the motion manner of planetary roller. With the change of rotation speed of main shaft, the action of gravity and centrifugal force on the abrasive particles inside the planet roller changes accordingly and the flowing state of the abrasive particle also changes. From this, the relative size of gravity and centrifugal force play a key

role for processing. Dimensionless parameters $\omega^2 r_0/g$ and $\Omega^2 R/g$ are the important parameters standing for rotational and revolution centrifugal force and represents the relative ratio of centrifugal force and gravity.

The motion manner of roller is determined by certain combination of rotation and revolution. The planetary transmission ratio ($I=\omega/\Omega$) is usually used to describe the relative ratio between the revolution and rotation angular velocity during the motion process of roller. Therefore, the ratio between rotation and revolution acted on the particle of unit quality ($\omega^2 r_0/\Omega^2 R$) and the planetary transmission ratio ($I=\omega/\Omega$) has the following relationship:

$$\frac{\omega^2 r_0}{\Omega^2 R} = \left(\frac{I}{I_0}\right)^2 = \frac{\left(\frac{\omega}{\omega_0}\right)^2}{\left(\frac{\Omega}{\Omega_0}\right)^2} \quad (1)$$

where Ω_0 , ω_0 and I_0 are characteristic rotational angular velocity and characteristics planetary transmission ratio.

$$\omega_0 = \sqrt{\frac{g}{r_0}}, \quad \Omega_0 = \sqrt{\frac{g}{R}}, \quad I_0 = \frac{\omega_0}{\Omega_0} = \sqrt{\frac{R}{r_0}} \quad (2)$$

Ω_0 , ω_0 and I_0 are determined by the mechanical structure and transmission characteristics of planet polishing machine.

If the reciprocal of the rotational angular velocity ω is used as the characteristics time and the radius of roller is used as the characteristic length, and after the momentum conservation equation for motion of liquid phase and particle phase[1] is changed to dimensionless form, all forms in the equations set do not change basically. The force item expression acting on the liquid phase and the particle phase demonstrates as the following after rewriting.

$$\begin{aligned} \vec{F}_{g,s} &= \alpha_s \rho_s \frac{g}{\omega^2 r_0} (\vec{g}^0 + \frac{\Omega^2 R}{g} \vec{R}^0) = \alpha_s \rho_s \left(\frac{\omega_0}{\omega}\right)^2 (\vec{g}^0 + \left(\frac{\Omega}{\Omega_0}\right)^2 \vec{R}^0) \\ \vec{F}_{g,l} &= \alpha_l \rho_l \frac{g}{\omega^2 r_0} (\vec{g}^0 + \frac{\Omega^2 R}{g} \vec{R}^0) = \alpha_l \rho_l \left(\frac{\omega_0}{\omega}\right)^2 (\vec{g}^0 + \left(\frac{\Omega}{\Omega_0}\right)^2 \vec{R}^0) \end{aligned} \quad (3)$$

where \vec{g}^0 and \vec{R}^0 stand for the unit vector of gravity acceleration and centrifugal acceleration of revolution.

It can be seen from formula (3) that the ratio between the centrifugal force and gravity $\Omega^2 R/g$ or $\omega^2 r_0/g$ is the important parameters that determine the motion mode and internal two-phase flow characteristic.

Determine the Duty Parameters

In order to investigate and make comparison for working process and mutual influence of different duty parameters, analysis and study for the flowing state of the liquid and particles in planet roller and the change of motion characteristics due to working conditions, 8 types of working conditions corresponding to 4 planetary transmission ratios have been selected. Where $\omega/\Omega=2/15$ is the planetary transmission ratio adopted by FY-VII type planet roll-polishing machine widely.

Table 1 provides the relative ratio between rotational angular velocity and the centrifugal acceleration of 8 working conditions.

Table 1 Angular velocity and centrifugal acceleration under 8 types of working conditions

ω/Ω	working condition	ω [rpm]	Ω [rpm]	$\omega^2 r_o/g$	$\Omega^2 R/g$
2/15	1	21	158	0.044	7.09
	2	36	266	0.13	20.1
1.00	3	158	158	2.51	7.09
	4	266	266	7.12	20.1
1.68	5	266	158	7.12	7.09
	6	447	266	20.1	20.1
2.83	7	447	158	20.1	7.09
	8	266	94	7.12	2.51

Force Analysis in Different Working Conditions

The value of planetary transmission ratio can be from zero to infinity. Zero and infinity correspond to two types of simple rotational modes with only revolution or rotation. In addition, the value of planetary transmission ratio has three special values. So, the value of planetary transmission ratio is divided into four ranges roughly. The three special values are:

- (1) $I=1$: The rotational angular velocity equals, namely $\omega = \Omega$;
- (2) $I=I_0$: the centrifugal acceleration equals, namely $\omega^2 r_o = \Omega^2 R$;
- (3) $I=I_0^2$: The tangential linear velocity equals, namely, $\omega r_o = \Omega R$.

Make a system of rectangular coordinates with $\Omega^2 R/g$ as horizontal coordinates and $\omega^2 r_o/g$ as longitudinal coordinates, shown as figure.1. Any point in the coordinates system stands for a type of working condition with different parameters. The line passing through the origin point stands for the operation working condition with same planetary transmission ratio. The action of gravity gradually reduces along the line direction with the increase of $\Omega^2 R/g$ and $\omega^2 r_o/g$. The slope of line reflects the action degree of rotational centrifugal force and revolution centrifugal force.

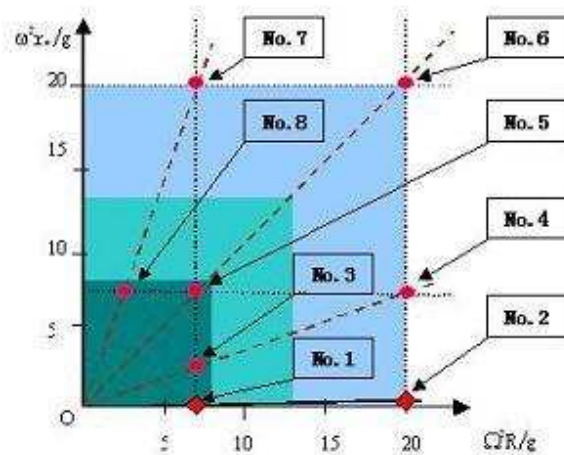


Fig.1 Calculation condition distribution relationship under 8 types of different working conditions

Calculation Example for Flow State Distribution of Different Working Conditions

Selection of Calculation Parameters. For easy comparison and analysis between the result of calculation simulation and experimental observation, a group of parameters that is similar to the experimental working condition is selected to be used for the primary simulation. The transmission ratio between the planet wheel and the center wheel is 2/15, and the revolution angular velocity is 158 rpm. The rotational angular velocity is -21 rpm (“-”stands for clockwise rotation). The radius of the connecting rod is 254mm and the radius of roller is 90mm. Therefore, $\Omega^2 R/g=7.1$ and $I_0=1.68$.

Calculating Result and Mechanics Analysis. (1) Working condition 1 and working condition 2. Fig.2 shows the concentration and velocity vector distribution of particle of grinding materials under No. 1 and No. 2. The speed of solid particle has large horizontal component at the boundary of two-phase of solid and flow and has large vertical component in the low concentration area of particles. If the radius vector of revolution is regarded as the boundary, the head-on revolution side are mainly fluid while the particles gather at the back side. At the bottom of the area where the particles gather at the back half side, the speed of particles and the fluid is almost zero, this indicates that they are in the state of relative rest. At the edge area of front half side, although the particles concentration is lower, the particles and the liquid have large tangential component. This means that the liquid with high movement velocity along the edge drives the particles to invade the edge area to form the end with S shape interface.

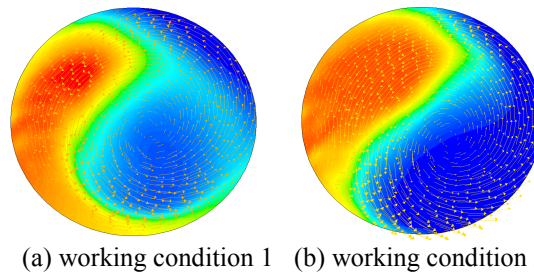


Fig.2 Concentration and velocity vector distribution of S type flowing state when transmission ratio is 2/15

(2) Working condition 3 and working condition 4. The flowing process of No.3 and No.4 corresponds to the condition that planetary transmission ratio $I=1$. According to the relationship given in formula (1), the ratio between revolution centrifugal force and rotational centrifugal force is still less than 1 when planetary transmission ratio $I=1$. Therefore, the revolution centrifugal force still plays a leading role. Figure.3 shows that the distribution boundary between particles and flow still exists, and the change of flowing state demonstrates unstable periodic evolution along with the change of running angle, the distribution presents R type flow state at different position.

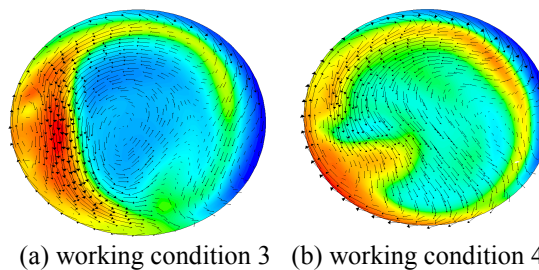


Fig.3 Concentration and velocity vector distribution of R type flow state when transmission ratio is $I=1$

(3) Working condition 5 and working condition 6. The flowing process of No.5 and No.6 corresponds to the condition of $I=I_0$. This means that the revolution centrifugal force and rotational centrifugal force play an important role in the flowing process. Figure 4 shows two flow states of the particles fluid under two working conditions.

(4) Working condition 7 and working condition 8. The calculating parameters of No.7 and No.8 is obtained when $I=I_0^2$. The rotational centrifugal force dominates in this moment. The concentration and velocity vector distribution takes on the concentric circles. The maximum speed appears on the boundary. The velocity vector is along the tangential direction of the concentric circles. Figure 5 shows the volume fraction distribution diagram of the flowing state of particles under No. 7 and No.8. The distribution takes on the O type flowing state of concentric circles when the full mixing is reached. The boundary between the particles and fluid takes on stables circular distribution.

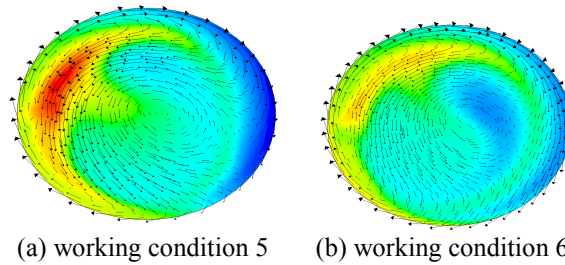


Fig.4 Concentration and velocity vector distribution of R type flowing state when transmission ratio $I=I_0$

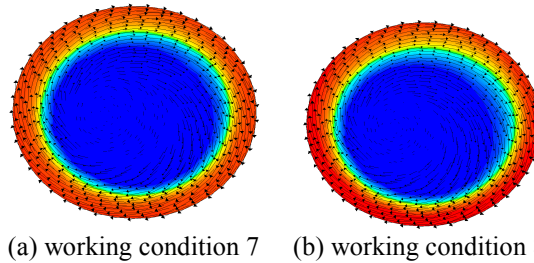


Fig.5 Concentration and velocity vector distribution of R type flowing state when transmission ratio $I=I_0^2$.

Conclusion

The flow state analysis of this paper shows clearly that figure.1 provides important theoretical value for centrifugal grinding processing. This figure can be used fully to optimize the design parameters of the equipment. For example, the centrifugal tumbling mill on the market at present usually works at the working condition 1. On the basis of above analysis, as the rotational velocity is very low and the group of grinding materials is relatively compact, the relative motion between particles is relative weak. Therefore, both the processing efficiency and processing quality are low.

The above analysis also shows that the planetary transmission ratio imposes obvious influence on volume fraction and velocity vector distribution of particles flow. With different planetary transmission ratio, the flow state characteristics of whole group of grinding materials differ greatly under the same working condition. The size and direction of the speed of particles have obvious change. It is concluded that these changes are the important factors affecting the processing.

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